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STATE OF THE ART
OF
RESEARCH AND DEVELOPMENT OF SOLAR ENERGY TECHNOLOGIES IN INDIA*

Prepared by

T. K. Moulik**

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** Professor, Indian Institut of Management, Ahmedabad, India

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Introduction

In India, Solar Energy was first harnessed during the early fifties, but did not gain much impetus. During recent years, increasing attention has been diverted towards renewable sources due to the sharp increase in oil prices, difficulties in producing and transporting increasing amounts of fossil fuels, supply uncertainties and environmental degradation caused by conventional fuels.

Solar energy is a major focus of non-conventional energy sources. It has applications in all sectors and is capable of supplementing existing sources of energy. It plays a pivotal role and has long been a part of the Indian way of life.

A number of reputed national institutions are involved in doing research and putting up field demonstration units to popularize non-conventional sources of energy.

The Commission for Additional Sources of Energy has taken up projects for the establishment of production facilities for solar cells, solar thermal systems and various other renewable energy devices. Today, India is capable of making solar photovoltaic devices and systems, solar water heating systems, solar crop dryers, solar stills, etc.

Inspite of all this, there is a great need to build up a countrywide infrastructure for production, distribution, sales and servicing of renewable energy systems and also to promote awareness of the role and potential of renewable energies and the importance of energy conservation.

The present paper highlights the importance of renewable energy sources by cataloguing various research investigations and field and demonstration trials which in their turn have created public awareness regarding these renewable energy sources.

Economic and Financial Constraints

- One of the most important constraints in the wider utilization of renewable energy sources is the high initial cost of the systems. At present, a solar device may cost more than a product based on conventional fuel. This acts as a deterrent to the potential users of renewable energy systems. On the other hand, the low level of production inhibits any cost reduction. This has become a vicious circle.

- These problems can only be overcome through technical improvement material and manufacturing development and a package of fiscal and other promotional measures.

- Incentives and subsidies introduced at the initial stages will help the new and renewable sources to become economically competitive.

Research and Development of Solar Thermal Energy

Despite various incentives and subsidies, the renewable energy sources have not been fully exploited. Thus, it would be desirable to concentrate on ways and means of minimizing the use of conventional energy by supplementing it with new and renewable sources of energy.

The Department of Non-Conventional Energy Sources has promoted and funded research and development activities in the area of Solar Thermal Conversion through various Universities, National Laboratories, with a view to developing newer materials and efficient systems and devices, improving reliability and performance of the systems and reducing costs. These research and developmental efforts include collection of basic metereological data like isolation, wind velocity, rainfall, relative humidity at various locations in the country which are the key factors for effective utilization of solar energy.

The thrust areas, in solar thermal energy conversion, include development of materials for efficient collector system, development of advanced collectors for medium temperature and high temperature output, development of solar refrigeration, air-conditioning systems, development of heat storage system and studies on systems engineering.

The Seventh-Five Year Plan document has outlined the importance of research and demonstration and field trials in creating public awareness towards renewable energy sources.

The Advisory Board on Energy has suggested tha t besides increasing the R&D efforts, a large number of systems may be installed through the demonstration programme as well as the extension programme of private users on a cost-sharing basis. The Board has also recommended that the facilities for soft loan finance may be provided for users of such systems. The Government has recently introduced additional subsidies and incentives for the promotion of Solar Thermal Systems. Hundred per cent subsidy is now available for installation of Solar Thermal Systems on public buildings where the cos t of conventional fuel and energy is paid from the Consolidated Fund of India. This has aroused considerable interest from various public and private industries and establishments like hotels, textiles, hospitals, etc. With this it is hoped that the Solar thermal programme will pick up and assume unprecedented proportions.

The overall objective of the Solar Thermal Programme is to develop systems through R&D activities, put up field demonstration units to collect performance data under actual field conditions and later on commercialize the systems for large scale utilization through an extension programme.

Work has been carried out in Institutions like

*National Physical Laboratory, New Delhi;
*Central Salt and Marine Chemicals Research Institute, Bhavnagar;
*Central Building Research Institute, Roorkee
*Central Arid Zone Research Institute, Jodhpur

on various problems including water heating, distillation, drying, cooling and space heating since early sixties but the work was scattered and sporadic.

At present the industrial organisations participating in the R&D activities are

- Bharat Heavy Electricals Limited
- Central Electronics Limited
- Tungabadra Steel Products Limited
- National Instruments Limited and

several other firms in the private sector.

Solar Water Heating Systems

They have become popular due to various technical and fiscal promotional measures. 460 solar water heating systems with a total capacity of 11,71,303 litres per day and approximately 24,147 m^2 collector area have been installed, uptil now.

- Two solar water heating systems of capacity 54,000 lpd with 1082m^2 of collector area were installed at Bhopal dairy, Madhya Pradesh, and
- Capacity 48,000 lpd with 1000m^2 collector area at Erode Textile Mills, Tamil Nadu.
- Solar Water Heating System of Capacity 2,000 lpd was installed at Air Force Missile School and Centre, Gopalpur on Sea, in Orissa.
- Another system of 2000 lpd at 65°C was installed at the Hindustan Organic Chemicals Ltd; Rasayani, Bombay. The hot water is being utilized for dissolution of sodium sulphite to be used in manufacturing operations of Meta Dinitrobenezene.
- Another system of capacity 2000 lpd was installed at Beggar Home, Delhi. Such a facility for poor people has been provided for the first time in the country.
- Four solar water heating systems of total capacity 1,76,000 lpd at 85°C with the collector area of 5614m^2 have been generated for Ordinance Factory, Itarsi, Madhya Pradesh.

*Solar Water heating system was installed for 68 quarters of Indo-Tibetan Border Police in Leh.

*Solar heating, cooling and hot water system was installed in the DNES building.

*Two solar water heating systems installed at Parag Dairy, Kanpur with (1) capacity of 50000 l/day to heat water to a temperature of 60°C; (2) capacity of 20000 l/day to heat water to a temperature of 85°C.

Solar Crop Dryers

*A pilot plant for tea drying was installed at Tocklai Tea Research Station, Jorhat in Assam.

*A 10-tonne per day grain drier has been installed in Ludhiana.

*A 30-tonne per day grain drier is installed at Allathur.

*Optimisation of Solar drying system for agricultural produce (in collaboration with the Colorado State University USA) Annamalai University.

*A wool drying plant was installed at Kambal Kendra, KVIB, Gwalior, Madhya Pradesh.

*Investigation of Solar Drying of Fish for Food and Feed, Indian Institute of Technology, Kharagpur.

*Utilization of Solar Energy for drying of Agricultural and food materials in improved solar dryers, Jadavpur University, Calcutta.

*Solar drying of Kendu Leaves; Science Technology and Environment Department; Orissa Government.

*Almost 30 solar kilns for drying timber with capacity of 7 cubic metres to 18 cubic metres have been installed in a few places and have shown promising results.

Solar Thermal Power Generation

*Development of a thermal storage system suitable for solar thermoelectric and total energy systems was installed Phase II - BHEL, Hyderabad.

*Effect on interstitial pressure and temperature on thermal conduction through porous and dispersed system and its application to solar thermal storage; University of Rajasthan, Jaipur.

*Test facilities for solar collector, NPL, New Delhi.

*Design, development and testing of paraboloid dish collector, BHEL, Hyderabad.

*Development, Optimisation and Study of solar thermal system using the linear solar concentrator, Indian Institute of Technology, New Delhi.

*Demonstration of a solar thermal power generation system for remote rural area, Jyoti Solar Energy Institute, Vallabh Vidyanagar, Kaira, Gujarat.

*Setting up of salt gradient solar pond for the dairy plant at Jamnagar for supplying of process heat for hot water and power gene ration design (Phase 1), GEDA, Vadodara and Gujarat Dairy Development Corporation, Gandhinagar.

*Proposal for development of a micro computer model of thermal behaviour of buildings, TRI, New Delhi.

*Status report with a view to designing standards for testing of Solar Thermal Devices, Indian Institute of Technology, Delhi.

Concentrating and Advanced Collectors

*For generating steam and providing heat in temperature range of 100-300°C, parabolic trough concentrating collectors with one axis tracking have been developed through an Indo-US Aid project.

*System for generating steam for use in a Silk factory in Mysore is under installation.

*Design, development, fabrication and testing of vacuum tube collectors. Phase II School of Energy Study, University of Poona, Pune.

*Installation of TAP collector for passive heating system and for ITBP quarters at Leh. Central Division, DPWD, Srinagar.

*Demonstration and development of low cost plastic solar collectors for air and water heating. Phase II, Indian Institute of Technology, Delhi.

*Three ton solar powered refrigeration plant for sub zero operating temperature, Vallabh Vidyanagar District, Kaira, Gujarat.

*Design, development and testing of a paraboloid dish collector, BHEL, Hyderabad.

Solar Cookers

The programme for manufacture and subsidised sale of solar cookers was launched in November 1981. So far about 46,000 solar cookers have been sold. Sales are executed through agencies designated by the respective state governments.

*Preparation of solar cooker status report, GEDA, Baroda.

*A Study on the performance of the Solar Cookers, MS University, Baroda.

*Design and Development of inexpensive solar cookers for application both in rural and urban houses, CES, IIT, Delhi.

*Comparative studies on the Nutritive value of the Food Using Solar and other fuels for cooking. Shri Parashakti College for Women, Courtallum.

Solar Refrigeration and Cooling

*Design and development of optimal continuous solar absorption refrigeration and air-conditioning systems (with James Cook University of North Queensland, Australia under Indo-Australia Programme of S&T, IIT Madras.

*Installation of a solarmeter chiller at Delhi Public School, RK Puram, New Delhi, SEC, New Delhi.

Other R&D Projects

*Project to survey alternative energy sources in the Kumaon hills, Department of Physics, DSB University, Nainital.

*Pilot plant for extraction of Ethyl Alcohol from Fermented Sweet Sorghum Juice by Solar Energy, Nimbkar Agricultural Research Institute, Phaltan.

*Development of solar dehydration system for field trials for dehydration of grapes to produce resin. University of Poona, Pune.

*Solar Desalination, IIT, Delhi.

*Augmentation of network of radiation stations of India, IMD, New Delhi.

*Study of the efficiency of the use of renewable source of energy in tea processing, NIDC, New Delhi.

Use of Solar Energy for Dairy Development

In order to promote the agricultural allied and ancilliary activities during the 1970's assistance was extended to small and marginal farmers and also agricultural labourers to purchase milch cattle. The purchase under the SFDA, and MFAL schemes was heavily subsidised. Apart from these incentives, the Government has also attempted to introduce solar energy to improve the dairy units efficiency. A number of demonstration

programmes have been launched by the Department of Science and Technology.

These solar installations propose to save a substantial amount of conventional fuel and to improve the profitability of the dairy units.

Parag Dairy at Kanpur has installed two solar water heating systems:

1 First of the capacity of 50000 l/day to heat water to a temperature of 60° C.

2 Second of the capacity of 20000 l/day to heat water to a temperature of 85°C.

Water heated to 60°C is used for washing and cleaning utensils, and the latter will be used as a boiler feed.

Solar Energy Centre

This Centre has been established to promote applications of solar technologies, through product development, systems engineering and development, testing and certification of materials, field demonstration testing and certification of solar components and systems,material components, product and system standardisation, arranging training courses and seminars and providing the necessary links between R&D organisations and Industries within and outside the country.

At present the Centre is functioning in a shed in District Gurgaon, Haryana. The permanent facilities for the Centre are being set up at Gwalpahari District, Gurgaon, but it is still under construction.

Solar Photovoltaic Systems

The concept of producing electricity directly from sunlight without the intermediate transformation to heat and mechanical energy is based on the "photovoltaic" effect. It has great potential in India where there is plenty of sun and a great need for electrical energy for decentralised applications. These systems are particularly suited for various rural applications as they provide for on-site generation of electricity. Various photovoltaic systems include - water pumpsets for micro-irrigation and drinking water supply, radio beacons for ship navigation at ports, community radio and television, cathodic protection of oil pipelines, weather monitoring, railway signalling equipment, battery charging etc.

The present cost of photovoltaics being fabricated in India is about Rs 100/- per peak watt. It is estimated that at a cost of about Rs 40 per peak watt, solar photovoltaic water pumping systems would become cost effective in comparison to the present day diesel pumpsets. Though initial costs are considered high compared to other systems based on conventional energy sources, they are competitive at current prices in certain remote areas which are not served by electric grids, where it is difficult to transport conventional fuels, and where power in small capacities is required.

The scope for utilization of these devices will increase with reduction in prices through technology development and increased production. India is one of the few countries in the world to have developed productive capability based on indigenous technique.

The PV Devices are portable, require no fuel, offer a pollution free source of power, they are easy to operate, maintenance free, have long effective life and are extremely reliable. These features make PV systems most suitable for installation in remote and isolated areas, forest and hilly areas and desert locations.

Research and Development

During the sixth five year plan, a comprehensive programme of research and development, pilot production and demonstration were implemented. This programme led to the development of indigenous technology for production, creation of initial infrastructure for the manufacture, installation and maintenance of photovoltaic systems and promoted awareness among potential users. These activities have been further diversified and expanded in the Seventh Five Year Plan.

*Silicon in different forms is the primary material used for solar cell production. Some projects relating to casting and directional solidification of silicon have been completed.

*An integrated programme on amorphous silicon solar cells has made steady progress. Plasma deposition facilities for experimental work have been established at Indian Association for Cultivation of Science, Calcutta, IIT, Delhi and University of Poona. New equipment has been ordered by National Physical Laboratory. Silane gas which is an essential input to amorphous silicon production has been produced in small quantities at IIT, Kharagpur and IISc. Bangalore and is being tested for its quality.

*Amorphous Silicon solar cell technology has also been identified as one of the Science and Technology Missions in the Seventh Plan. The DNES has proposed to set up a pilot plant for making amorphous silicon solar cells and modules. A preliminary project document has been prepared and forwarded to UNDP for possible assistance regarding the equipment not made in India.

*Research on other aspects of PV technology like photoelectrochemical solar cells, thin film devices based on compound semiconductor materials such as copper indium diselenide on implantations and laser annealing, system development etc. are also being supported.

*The R&D programme also covers testing and evaluation of deep-well pumps and medical refrigerators. Import of photovoltaic modules from 7 foreign manufacturers is being arranged for purpose of evaluation and trial in Indian conditions.

NASPED Programme

A five-year National Solar Photovoltaic Energy Demonstration (NASPED) programme was sponsored by the Department of Non-Conventional Energy Sources at the Central Electronics Ltd. Sahibabad from October 1980. The main objectives of the programme were the establishment of pilot production facilities for solar cells and modules and the development and demonstration of PV systems for various applications. The pilot production has led to the establishment of production facilities on commercial lines. The achievements of the programme are as follows:

- Technology for solar cells and module production was developed from bench scale to commercial scale production.
- Variety of systems have been designed, developed and field tested which include water pumping systems for drinking water supply and micro irrigation, street lighting units, community lighting systems, community TV etc.

- The programme has helped to create a pool of technical manpower capable of technology development, systems engineering, production management.

- A total of 401 systems were supplied under the NASPED programme between April and September 1985. These included 246 pole-mounted street lighting units, 47 water pumping systems and 101 TV systems.

Demonstration Activities

There has been a significant rise in the demonstration activities. The following are the highlights of these activities:

1 Village Electrification

After the successful demonstration of photovoltaic powered street lighting units Salojipally village in Andhra Pradesh and five other villages in Tamil Nadu more installation of street lighting units in village Orcha in the Bastar District of Madhya Pradesh were arranged.

A programme for installation of solar powered street lights in 250 villages was taken up during 1984-85 through the Rural Electrification Corporation, State Electricity Boards, and Nodal Agencies of some of the State Governments.

2 Centralised PV Systems

A central PV power system has been installed in the Village Achheja in Gaziabad district of UP to provide power for about 30 street lights and community TV and radio sets. A PV water pumping system has also been installed. An experimental programme is also being taken up in co-operation with Rural Electrification Corporation in respect of 4 villages.

3 Water Pumping Systems

A special project for the demonstration and popularisation of solar photovoltaic water pumping systems was taken up in the States of Andhra Pradesh, Bihar, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal by a recommendation made by the Advisory Board on Energy. This programme of demonstration and field trial is being expanded and arrangements are being made for the supply of 300 pumping sets.

4 Community TV Sets

A total of 200 PV powered direct reception sets are being installed by Doordarshan in Uttar Pradesh and Bihar. The PV power packs for these systems have been supplied with the support and sponsorship of DNES. These systems enable uninterrupted viewing of TV broadcasts received directly from INSAT-1B.

Industrial Production

DNES is responsible for regulating the industrial and import licensing of solar photovoltaic devices.

- During the year Central Electronics Ltd. (CEL) has installed new equipment for production of modules and cells and is expected to achieve a total cell production capacity of 2MW and module production capacity of 1.35 MW by March 1986. Lamination technology has been introduced into production. The production at CEL between April and December 1985 amounted to 243 KW. The production at BHEL during the same period was approximately 70 KWp.

  Rajasthan Electronics and Instruments Ltd. has also commenced production.

- Both CEL and BHEL make supplies for photovoltaic systems for specialised applications like telemetry power supplies for off-shore oil platforms and communications.

The systems supplied by CEL and BHEL during the year 1985-86 are as follows:

System	CEL	BHEL
Water Pumping Systems	69	35
TV and TV-cum-Lighting Systems	212	1
Community Lighting Systems	7	-
Street Lighting Units	637	338
Systems for off-shore oil platforms	-	6
Modules for Battery charging units	300	300
Other Systems	27	1

A BHEL-made PV system for battery charging has been successfully used by the Indian Expedition to Antartica in 1985-86.

Annex I

List of R&D projects supported by DNES in the year 1985-86

Title of the Project	Institution
Crystalline and Poly-Crystalline Silicon (Material/Device)	
• Production of Solar Grade Silicon by hot metal Solvent extraction and directional solidification	RRI, Bhubaneshwar
• Studies on Poly-Crystalline Silicon for photo-voltaic Solar Energy Conversion - Phase II	NPL, New Delhi
• Electrowinning of High purity, low cost Silicon suitable for Solar Cell Devices	Anna University, Madras.
• Polycrystalline Silicon from Rice-Husk	IIT, Kharagpur.
Amorphous Silicon Solar Cells	
• Development of Amorphous Silicon thin film solar cells.	IACS, Calcutta.
• Research, Development and Production of Amorphous Silicon Solar Cells	University of Poona, Pune.
• Development of Amorphous Silicon Solar Cells	IIT, New Delhi
• Development of the techniques for production operation and storage of silanes from rice husk for preparing a-si.	IIT, Kharagpur
• Production of Silanes foramorphous silicon and polysilicon applications.	IISc., Bangalore.
• Amorphous Silicon Solar Cells - Development and Evaluation Studies.	IIT, Madras.
• Investigation on hydrogenated Amorphous Silicon films.	NPL, New Delhi.

Photoelectrochemical Cells

• Photoelectrochemical conversion and storage of Solar Energy.	BHU, Varanasi
• Photoelectrochemical Solar cells using transition Metal Dechalcogenide Crystals.	Sardar Patel Univ., Vallabh Vidyanagar
• Solar Energy Conversion using Narrow Bandgap semiconductor Electrodes in Photoelectrochemical cells.	Gorakhpur Univ., Gorakhpur.
• Solar Energy Conversion through photoelectrochemical systems.	IISc. Bangalore.
• Studies in photochemical conversion of Solar Energy.	MLS University, Udaipur.
• Energy conversion in Photoelectrochemical systems.	IIT, Delhi.
• Photoelectrochemical Energy Conversion.	IIT, Delhi.

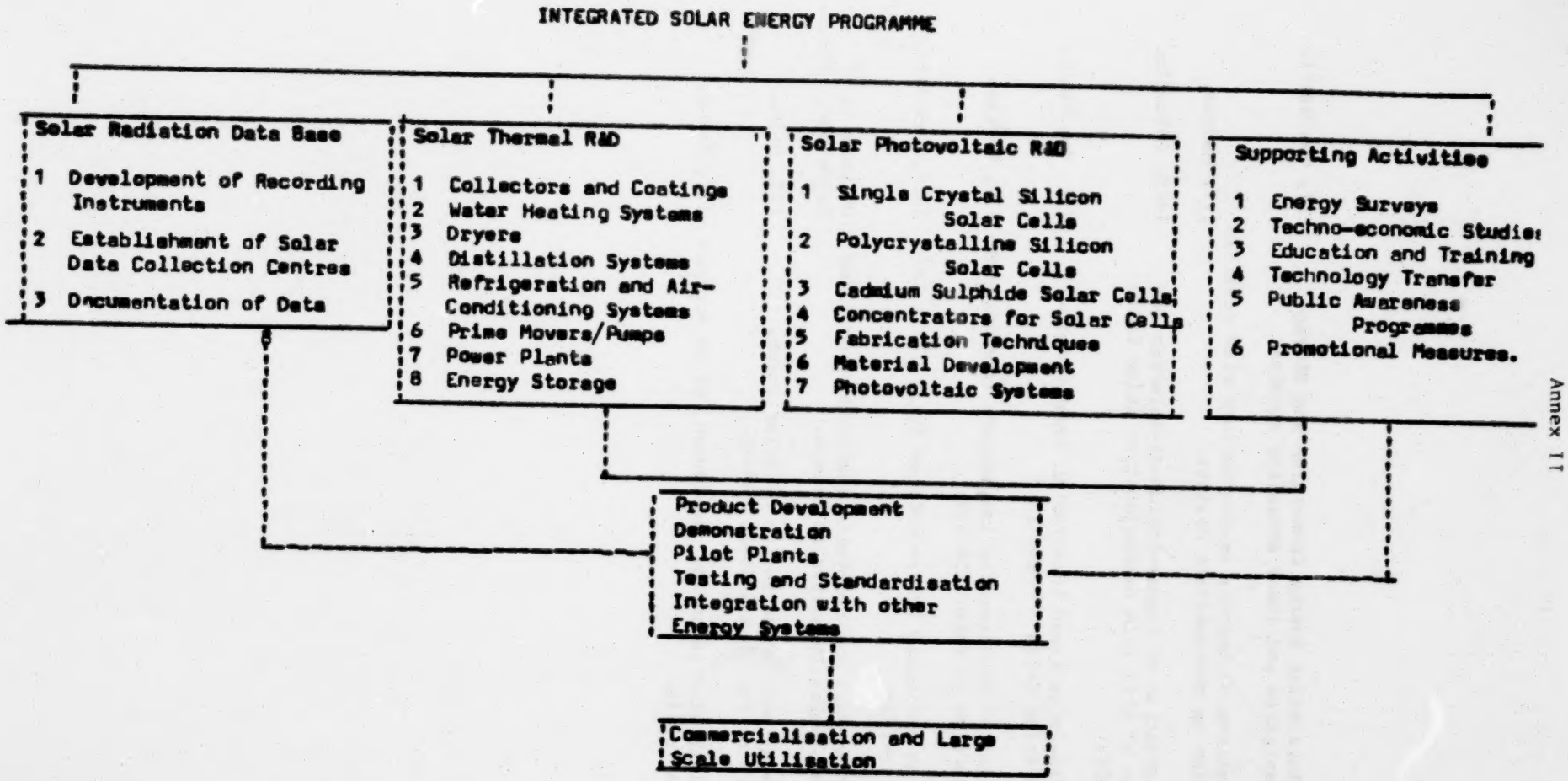
Photovoltaic Systems

• Development and Demonstration of Concentrator Photovoltaic Systems for specific stand alone rural applications.	Kalyani University, Kalyani.
• Photovoltaic solar Electric Power for Rural Development in Sunderban	Bidhan Chandra Krishi Vishwa Vidyalay, Kalyani.

Other Projects

• Development of thermoelectric generators for Solar (and other) energy conversion - Phase II	IIT, Kharagpur.
• Study on large area Semiconductor liquid junction Photovoltaic Cells.	Shivaji University, Kolhapur.

• Photovoltaic Solar Energy Conversion and Storage ion implantation and laser annealing studies.	IIT, New Delhi.
• Investigations on ternary semiconductors with possible application as photovoltaic devices.	IIT, Madras.
• Characterization of Copper-Indium-Di-Selenide and formation of thin film heterojunction Solar Cells: Cds:CuInSE.	IACS, Calcutta.
• Indium-Tin-Oxide based interfacial layer Hetero-junction Solar Cells - Phase II.	IIT, New Delhi.
• Development of Non-tracking luminescent concentrators for Conversion of Solar Ene rgy.	IIT, Madras.
• Studies on InP based heterojunction Solar Cells InP/ ITO and INP/Cds.	IACS, Calcutta.
• Study of Ternary chalcophyrite semiconducting films as photovoltaically active materials.	University of Rajasthan, Jaipur.
• Development and demonstration of solar energy concentrator for Photovoltaic Panels.	IIT, Delhi.
• Feasibility studies on the development of an organic dye solar cells.	IIT, Delhi.


INTEGRATED SOLAR ENERGY PROGRAMME
Solar Radiation Data Base
1 Development of Recording Instruments
2 Establishment of Solar Data Collection Centres
3 Documentation of Data
Solar Thermal R&D
1 Collectors and Coatings
2 Water Heating Systems
3 Dryers
4 Distillation Systems
5 Refrigeration and Air-Conditioning Systems
6 Prime Movers/Pumps
7 Power Plants
8 Energy Storage
Solar Photovoltaic R&D
1 Single Crystal Silicon Solar Cells
2 Polycrystalline Silicon Solar Cells
3 Cadmium Sulphide Solar Cells
4 Concentrators for Solar Cells
5 Fabrication Techniques
6 Material Development
7 Photovoltaic Systems
Supporting Activities
1 Energy Surveys
2 Techno-economic Studies
3 Education and Training
4 Technology Transfer
5 Public Awareness Programmes
6 Promotional Measures.
Product Development
Demonstration
Pilot Plants
Testing and Standardisation
Integration with other Energy Systems
Commercialisation and Large Scale Utilisation